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ABSTRACT

This fourth in a series of six modules for a course titled Nondestructive Examination (NDE) Techniques II describes the specific technique variables and options which are available to the test technician, provides instructions for selecting and operating the appropriate test equipment, describes physical criteria for detectable discontinuities, defines and describes non-relevant indications, and describes specific types of relevant discontinuities which require detection, interpretation, and evaluation. The module follows a typical format that includes the following sections: (1) introduction, (2) module prerequisites, (3) objectives, (4) notes to instructor/student, (5) subject matter, (6) materials needed, (7) procedures, (8) data table, (9) reference materials, (10) test. (The course is one of fifteen technical courses for the second year of a two-year postsecondary curriculum in Nuclear Quality Assurance/Quality Control Technology.) (LRA)

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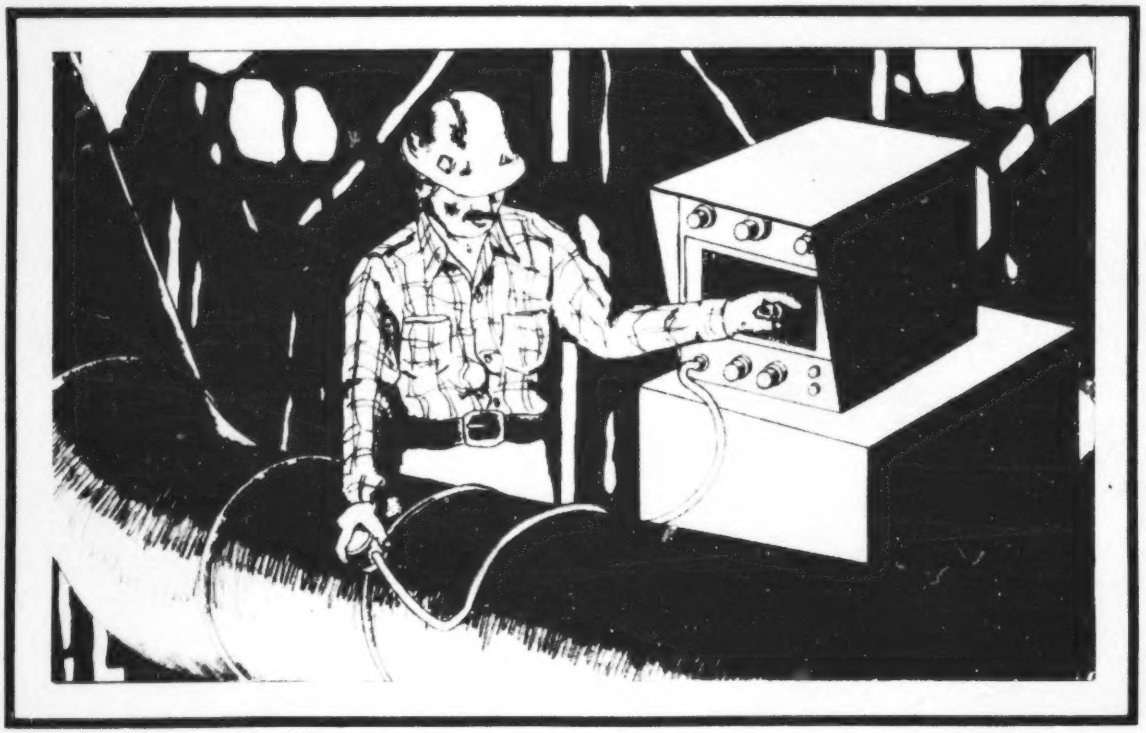
NUCLEAR TECHNOLOGY

COURSE 32 NONDESTRUCTIVE EXAMINATION (NDE) TECHNIQUES II

MODULE 32-4 Operation of Magnetic Particle Test Equipment



CE 024 296

GENERAL PHYSICS CORPORATION
Columbia , Maryland

COURSE MODULES

COURSE 32 NONDESTRUCTIVE EXAMINATION (NDE)
TECHNIQUES II

Module 32-1 Fundamentals of Ultrasonic Testing
Module 32-2 Operation of Ultrasonic Test Equipment
Module 32-3 Fundamentals of Magnetic Particle Testing
Module 32-4 Operation of Magnetic Particle Test Equipment
Module 32-5 Fundamentals of Eddy Current Testing
Module 32-6 Operation of Eddy Current Test Equipment

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This module was prepared for General Physics Corporation by Richard Groseclose, General Physics Corporation.

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INTRODUCTION

The Nuclear QA/QC Technician can have duties which require him or her to qualify as a Level I or Level II magnetic particle inspector. Such qualification requires the ability to operate magnetic particle equipment in accordance with written procedures.

Magnetic particle testing is an extremely useful and relatively simple means of examining ferromagnetic materials for a variety of discontinuities. This module describes the specific technique variables and options which are available to the test technician, provides instructions for selecting and operating the appropriate test equipment, describes physical criteria for detectable discontinuities, defines and describes non-relevant indications, and describes specific types of relevant discontinuities which require detection, interpretation, and evaluation.

MODULE PREREQUISITES

The student/trainee should have prior training or experience on fundamentals of magnetic particle testing. Completion of Nuclear Technology, Module 32-3, Fundamentals of Magnetic Particle Testing, satisfies this prerequisite.

OBJECTIVES

Upon completion of this module, the student/trainee can:

1. Successfully complete a written examination which consists of questions selected from the Level II SNT-TC-1A certification written test.
2. Demonstrate a knowledge of magnetic particle test equipment operation by inspecting selected parts.
3. List typical discontinuities found in various materials resulting from inherent, processing and service defects, and describe the corresponding indications produced from magnetic particle examination.
4. Describe appropriate magnetic particle tests as listed below for different test specimens with known defects:
   a. magnetization with prods, dry particle method
   b. magnetization with coil, wet particle method
   c. magnetization with yoke, dry particle method
   d. magnetization with prods, wet fluorescent
5. Select for each test in objective #4 the appropriate test equipment, calculate current requirements, adjust equipment properly, induce magnetic field correctly, apply test medium in recommended manner, and evaluate test indications.

MAGNETIC PARTICLE TESTING TECHNIQUE VARIABLES

Scope

Many variations in testing techniques are available to the technician or inspector, and must be evaluated before beginning a test. The technique selected must be appropriate for the test specimen and types of test equipment available. In addition, the technique must assure adequate sensitivity and reliability. With regard to the test specimen, the specimen size and shape, type of ferromagnetic material, and type of defects sought must be considered.

The variations which require evaluation include:

- Type of current - The type of current is limited by the equipment available. Most equipment has output terminals for alternating current (AC) and for half-wave rectified single phase direct current (HWDC). Also, equipment may be available which supplies three phase rectified direct current or rectified and filtered current which is direct D.C.
- Type of particles and method of application - Magnetic particles may be applied by the dry method or the wet method. Particles may be colored or fluorescent, the type of particles must be compatible with the method of application and equipment.
- Sequence of steps - Particles may be applied by the continuous method which is concurrently with the application of te magnetizing force. Particles may be applied by the residual method, which is after the current has been turned off.
- Direction of field - The type of magnetic field, such as circular or longitudinal, should be appro-

priate for the configuration of the specimen. The methods and locations of making contact or using a coil are to be considered.

- Sensitivity - The sensitivity of the test is governed by a combination of factors: magnetizing force intensity, test medium characteristics, method of application, specimen configuration, and surface finish and condition.
- Equipment - Type of power unit, prods, coils, yokes and other equipment must be selected such that the correct test with proper sensitivity is conducted.

Magnetizing Current and Magnetic Particle Application

The two basic decisions which must be made by the technician or inspector before selecting specific types of test equipment are the (1) type of current to be used, and (2) type of magnetic particles to be used. Table 32-4-1 lists the general types of defects sought, and in the order of preference, the recommended types of magnetic particles and current.

In determining the method and sequence of magnetic particle application, the type of material must be considered along with the characteristics of the residual method and the continuous method.

Residual Method

The residual method can be used only on materials with sufficient retentivity to produce leakage fields at discontinuities. Hard materials which have high retentivity usually are low in permeability and require very high magnetizing fields to produce satisfactory results. When the magnetizing force is removed from a part, the residual magnetism in the part is always less than the field present when the force was acting. The amount of

Table 32-4-1 List of Defects and Recommended Magnetic Particle/Magnetizing Current Types

Type Defect Sought	Type Magnetic Particles	Type Magnetizing Current
Very fine, shallow, surface defects	1. Wet method, fluorescent 2. Wet method, non-fluorescent 3. Dry powder	1. A.C. 2. HWDC
Coarse surface defects	1. Dry powder 2. Wet method	1. HWDC 2. 3-phase rectified A.C. 3. Straight D.C. 4. A.C.
Sub-surface	1. Dry powder	1. HWDC 2. 3-phase rectified A.C. 3. Straight D.C.

magnetic field loss depends on the retentivity of the material.

Continuous Method

The continuous method provides greater sensitivity than the residual method, because the magnetic particles are applied when the magnetic field is at maximum strength. Maximum sensitivity can be obtained for very fine defects by immersing the part in a wet bath, passing the magnetizing current through the part for a short time while immersed, and allowing the current to remain on while the part is withdrawn from the both for draining. When immersion is not practical due to the size of the part, the wet bath can be sprayed on and allowed to drain off while the current is on.

Direction of Field

The next variable that must be evaluated by the technician is the direction of the magnetic field. In order for a discontinuity to produce a visible indication, it must intersect (cross) the magnetic lines of force. If the discontinuity lies parallel to the flux lines, a magnetic polar condition, which will attract magnetic particles, will not be established, and an indication will not be produced. In most cases, it is recommended that each specimen be magnetized twice (in different directions) during the examination in order that all possibly present discontinuities may be located. Fields are advised by either the circular or longitudinal method.

Circular Magnetization

Of the two types of magnetization, circular is frequently preferred because it produces a minimum of external polarity that can attract and hold particles where no discontinuity exists. When passing a current through a specimen to produce a circular field, it should be remembered that discontinuities which are roughly parallel to the current (perpendicular to the magnetic field) will be detected. Those which are perpendicular to the current may not be detected.

The strength of the magnetizing current used on any specimen should not exceed the value needed to produce indications of the discontinuities which are sought. The required current values for circular magnetization vary because of differences in alloys and shapes. For regularly shaped parts (such as bars, rods, cylinders, etc.), the rule of thumb is to use the following current values:

- When using half-wave D.C., use from 800-1000 amperes per inch diameter or cross section.

- When using A.C., use 500-600 amperes per inch diameter or cross section.

These values may be used whether the parts are magnetized by passing the current directly through the part, as in a "head short", or by placing a hollow part (or a part with a hole) on a "central conductor". Approximate magnetizing current values for these type of specimens are listed in Table 32-4-2.

Table 32-4-2 Magnetizing Current, Circular Method, for Solid and Tabular Specimens

Greatest Width or Diameter, In Inches	Magnetizing Current In Amperes (Max.)	
	HWDC	AC
1/2	500	300
3/4	750	450
1	1000	600
1 1/2	1500	900
2	2000	1200
2 1/2	2500	1500
3	3000	1800
3 1/2	3500	2100
4	4000	2400

When testing is performed on many similar parts, such as in a manufacturing operation, a "standard", or test specimen with a typical indication should be used for reference and checked from time to time. The "standard" may be used to adjust the current to obtain optimum sensitivity to the types of discontinuities which are sought.

Longitudinal Magnetization

Longitudinal fields may be induced in small parts using fixed coils, but for large specimens, coils of heavy electrical cable (such as welding lead cable) are wrapped around the part. The effective magnetic field created in the part is determined by the product of the number of amperes and the number of turns in the coil (ampere-turns). For example, a 6 turn coil carrying a current of 1,000 amperes produces a magnetizing force of 6,000 ampere-turns.

Effective coil magnetization is also dependent on the specimen shape and in particular, the relationship of the specimen's length to its diameter. This relationship is known as the length/diameter (L/D) ratio of the part. Generally, the longitudinal axis of the part must be parallel to the magnetizing force, and the L/D ratio must be between 2 and 15. For example, a bar to be tested is 18" long and 6" in diameter. The L/D ratio is 18/6, or 3. This is an acceptable ratio for coil magnetization. In most cases, the area to be examined at one time should be limited to 18".

When a fixed coil is used, the specimen should be held against the inside wall of the coil and not positioned in the center of the coil. A maximum flux field is produced in the part when the cross-sectional area of the part does not exceed 1/10 the area of the coil operating.

The rule of thumb for calculating the required ampere for coil magnetization, longitudinal method, is represented by equation 32-4-1.

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$$\text{Amperes} = \frac{45{,}000}{(L/D)} \times \frac{1}{T}, \text{ or } \frac{45{,}000\ D}{LT} \qquad \text{Equation 32-4-1}$$

Where:

45,000 = Constant

L = length of specimen

D = diameter of specimen

T = number of turns in the coil

Example

Problem: Determine acceptability of longitudinal magnetization and value of magnetizing current.

Given: A test specimen is 15" long and 5" in diameter. A coil is available consisting of 10 turns. The various values, then, from the equation 32-4-1 are:

45,000 = Constant

L = 15"

D = 5"

T = 10

Solution

The L/D ratio = 15/5 = 3, which is acceptable for coil magnetization. The required amperage, then, is calculated as follows:

$$A = \frac{45{,}000\ (5")}{(15")\ (10\ \text{turns})} = \underline{1500\ \text{amperes}}$$

When inspecting a multiple-diameter specimen, it is recommended that the part be first magnetized with a current value as calculated for the smallest diameter of the

part and inspected. The current required for the next larger diameter should then be calculated, and the part re-magnetized and that value and re-inspected. The part should be inspected in this manner once for each significant different part diameter, to assure proper field strength and test sensitivity in all areas of the specimen.

Prod Magnetization

Prod magnetization is a method of producing a circular field in a part, but the resultant field is actually distorted-circular, due to the poles created at the contact points. It has been shown in practice that prod spacing should usually be maintained between 2 and 8 inches. When inspecting plate-type materials, the current values shown in Table 32-4-3 usually produce satisfactory results. For inspecting large specimens, the rule of thumb is to use approximately 200 amperes per inch of prod spacing as a starting value. If the initial setting produces an excessive accumulation of particles between the points of the prods, the field strength is too great. In this case, either the current should be lowered, or the prod spacing should be increased.

Table 32-4-3 Recommended Prod Spacings and Current Values

Prod Spacing, Inches	Section Thickness, Inches	
	Under 3/4 inches	3/4 inch and over
2 to 4	200 to 300 Amperes	300 to 400 Amperes
>4 to <6	300 to 400 Amperes	400 to 600 Amperes
6 to 8	400 to 600 Amperes	600 to 800 Amperes

SELECTION AND OPERATION OF TEST EQUIPMENT

Scope

The various types of equipment most used for magnetic particle examination involve sections of power, units, prods, coils, yokes, and ultraviolet lamps. Characteristics of these items and techniques for their use are described in this section.

Power Units

Power units are used to provide the magnetizing current for testing with the coil, direct induction, or central conductor magnetizing techniques. The typical power unit consists basically of a step-down transformer, rectifier, and current off-on switching devices. Low voltage output is utilized to assure operator safety and to minimize arcing at contact points on the test specimen. Most units have variable power outputs. Typical portable power supplies have a range of about 100 to 1,000 amperes. Large units are available in many sizes, and may be designed to produce upwards of 20,000 amperes of current output.

There are three basic types of power units: the portable unit, the mobile unit, and the stationary unit. Each of these units usually has the following features:

- power on-off switch (power supply to unit)
- adjustable output (test) current control
- output (test) current ampere meter
- output terminals for AC current and some form of DC current (HWDC, straight DC, 3 phase rectified DC, etc.)
- switching device or connection for microswitch leads for switching output (test) current on and off

The portable units and mobile units are readied for service by (1) attaching the cable leads (for the coil or prods) to the appropriate output terminals, (2) connecting the microswitch leads to the unit, and (3) connecting the unit to the electrical service supply. When the unit is switched on, it is ready to operate. Before attempting to magnetize a part, the operator should check the operation of the unit to verify that it is operating satisfactorily. This may be done by (1) touching the prods together (if prods are used) or checking to be sure that the coil is connected, (2) depress the microswitch (which is sometimes located in one of the prod handles), causing current to flow, and (3) observing the output current meter for a meter reading which is representative of the output current setting. If a steady indication is obtained without fluctuation or erratic operation, the electrical connections are apparently properly secured and the equipment is ready for use. The operator then adjusts the output current control to the value needed to magnetize the particular part, and proceeds with the test.

Stationary units may be standard manufactured testing units, or custom manufactured units designed to test particular types of specimens. The typical stationary unit is capable of magnetizing specimens ranging from a few inches to 5 or 6 feet in length. Most stationary units are equipped with adjustable "head stocks" for clamping and holding specimens. The "head stocks" are actually integral electrical conductors or electrodes which contact the specimen and provide the electrical connection for passing a magnetizing current through either the specimen or a control conductor. Separate cables to coils or prods usually are not used with stationary units.

Stationary units are usually designed and equipped to use primarily the wet batn inspection method. As such, each is equipped with a reservoir for the inspection media (fluid), and pumping device, and a hose and nozzle used for flowing the liquid onto the specimen.

A magnetizing/demagnetizing coil is generally included as an accessory on most stationary units. The electrical controls on the unit are usually arranged so that the coil may be energized with either A.C. or D.C. current, as selected by the operator.

Some of the other features, which may be included on stationary units, and their functions, are listed in Table 32-4-4.

A test is normally conducted on a stationary unit as follows:

- Turn main power switch on the energize unit.
- Turn on inspection-bath pump and agitator. Allow the inspection-bath liquid to mix and circulate for approximately 10 minutes (or as recommended by the equipment manufacturer) prior to using for inspection. The inspection-bath is a suspension of very fine magnetic particles in a liquid vehicle, usually light oil or kerosene. To achieve the required test sensitivity, the degree of particle concentration must be correct, and should be checked daily before testing begins. The bath is usually checked by performing a settling test. This is done by pumping a small representative sample (about 100cc) of the suspension into a graduated centrifuge tube, allowing the particles to settle, and observing the quantity in the tube. The recommended concentrations for these wet suspensions, as measured on a 100 cc sample by a settling test are:

Table 32-4-4 Typical Stationary Power Unit Features

Feature	Function
• DC Pilot Light	Indicates DC output current
• AC Pilot Light	Indicates AC output current
• Block Light	Fluorescent particle inspection technique
• Hood and Curtain	Encloses unit and operator, to allow "black light" inspection
• Demag Current Pilot Light	Indicates demagnetization output current
• AC Transfer Switch	Selection of head stock contacts or coil connection for AC output current
• Timed Magnetizing Current Control	Applies timed magnetizing current
• Automatic Demag Cycle Control	Provides automatic coil demagnetization
• DC Transfer Switch	Selection of bead stock contacts or coil connection for DC output current
• DC-AC Selector Switch	Operates current-type selection
• Control Cable Connection	Connection for external control switch
• 110 VAC Outlet	Convenience outlet
• Line Pilot Light	Supply voltage indicator
• Pump Switch	Control inspection bath pump
• AC Ammeter	Indicates strength of AC output current
• DC Ammeter	Indicates strength of DC output current
• Magnetizing Current Pilot Light	Indicates when magnetizing current is on

- Nonfluorescent particles - 1.7-2.4 cc particles/100cc
- Fluorescent particles - 0.2-0.5 cc particles/100cc
- Set AC-DC current selector switch as required.
- Set current transfer switch to feed power to either the heat stocks or the coil, as selected for the test.
- Set the test specimen in place for testing by either (1) clamping in between the head stocks, (2) placing on a central conductor, clamped between the head stocks, or (3) placing in the coil with the ends resting on the support ledges of the head stocks.
- Set the current control at the proper amperage setting.
- Set the magnetizing current timer (if applicable).
- Apply the magnetizing current by activating the control switch.
- If the continuous method is used, flush the wet bath (inspection media) over the part while the magnetizing current remains on.
- If the residual method is used, flush the wet bath over the part after the magnetizing current has been started and stopped.
- The specimen is now examined for discontinuities.
- Following the examination for discontinuities, it is recommended that the specimen be re-magnetized in another position or another direction, and re-inspected.

Prods

Prods, whether individual prods or the dual-prod assembly type, are equipped with heavy power cables and a remote control switch cable. Prods are usually used only

with portable or mobile power units. When the power cables are connected to the selected output terminals, and the remote control switch cable is connected to the control outlet on the power unit, the prods are ready for use. Before beginning a test, it is customary to check the equipment for proper operation. This may be done by (1) turning power unit "ON", (2) touching prods together, or touch both electrodes to a piece of steel or other conductive material, and (3) observe the output ampere meter for a steady current-flow indication when the remote control switch is depressed.

After checking the equipment, the technician may proceed with the test in the following steps:

- Examine the specimen for size and shape.
- Set the power unit for the recommended output current.
- Magnetize the specimen by pressing the prod trips on the specimen at the appropriate locations (while maintaining proper spacing), and pressing the trigger or remote control switch to turn on the magnetizing current.
- Apply the magnetic particles by either the continuous or the residual magnetism method (the continuous method is usually preferred for the large specimens and for the inspection of welds.)
- Examine for discontinuities.
- Re-examine the same area by re-magnetizing in a different direction (by rotating the prod locations about 90° and re-examining to assure that all discontinuities are indicated.)

Coils

Coils may be used for both magnetizing and for demagnetizing parts, and may be one of several types:

- Fixed AC current coils, which plug directly into a 110 VAC receptacle
- Fixed AC or DC coils mounted on stationary power units
- Fixed AC or DC coils, with cable leads for use with portable or mobile power units
- Coils formed by draping or wrapping cable turns around a specimen

For magnetizing parts, coils work most effectively on specimens whose cross-sectional area is about 1/10 the area of the coil opening or less. For a typical fixed coil of approximately 10" diameter opening, therefore, it would operate most effectively on specimens up to about 3" in diameter. When this relationship of specimen diameter to coil diameter is exceeded, a coil formed with cable turns should be used. This method of forming a coil is illustrated in Figure 32-4-1.

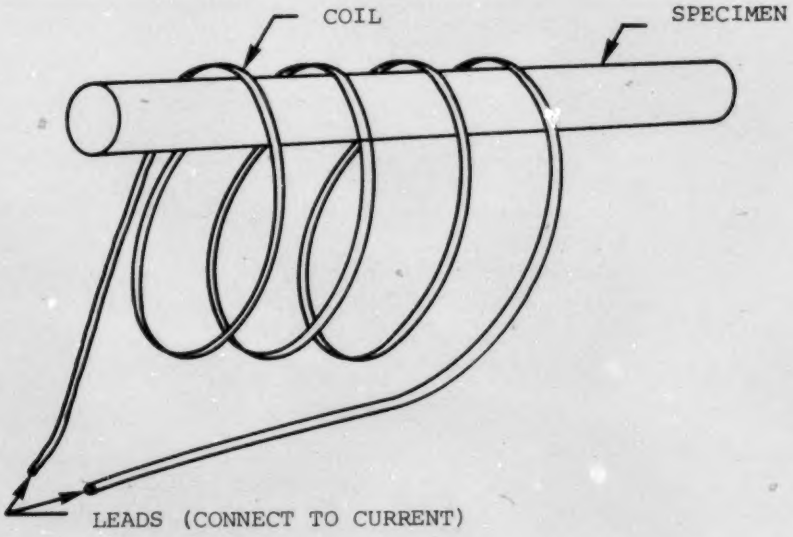

Figure 32-4-1 Cable-Type Coil

Coils are used in performing magnetic particle tests in the following manner:

- Connect coil to power source.
- Position the specimen in the coil, with the specimen touching the coil on one side.
- Examine the specimen and calculate the required amperage (considering part size and number of coil turns), when a variable power source is used, and set the proper value on the power unit current control. (There is no adjustment for fixed coils which plug directly into 110 VAC.)
- Energize the coil, and magnetize the specimen.
- Apply the magnetic particles by either the continuous or the residual magnetism method.
- Examine for discontinuities.

Any of the coils mentioned above can also be used for demagnetizing parts. The basic method of reducing or eliminating a residual magnetic field in any specimen is to subject the specimen to a continuously reversing magnetic field which gradually reduces in strength. This procedure causes a corresponding reversal and reduction of the field in the specimen.

The simplest and most convenient method of demagnetization is to use the fixed AC coil. With this method, the part is slowly passed through the energized coil and withdrawn from its influence. Since the direction of the current flow in the coil reverses itself continuously, the field in the specimen is also reversed, and as the part is moved away from the coil, the field is reduced to an insignificant level. The only drawback to this method is the fact that since AC current does not produce a deeply penetrating magnetic field, the method usually is effective only for small parts.

Large, heavy, or unusually shaped specimens can be demagnetized with the other types of coils, using DC current, if the power unit has provisions for very fine current control and a switching device for reversing the current. If the power unit is not equipped for automatic demagnetization, it may be accomplished as follows:

- Position the specimen in a coil, connected to DC or HWDC current.
- Adjust current control to a value at least as great as that which was used to magnetize the part.
- Give the coil a "shot" of current at that value.
- Reverse the direction of the current (use the current-reversing switch, if applicable; if not, reverse the cable leads connected to the output terminals), and reduce the current setting.
- Give the coil a "shot" of current at the new setting.
- Repeat the "reversing, reduction and shot" action in about 30 increments until the current setting is down to zero. (Commercial, stationary power units are frequently equipped with automatic 30-step switches for this purpose).

The foregoing demagnetization method works well for small parts in standard coils and for large parts with a full length cable-wrap coil. If an objectionable field still exists in large, hard parts, it is advisable to use the through-current technique whereby the magnetizing current is passed through the part with the "reversing, reduction and shot" method employed.

Yokes

Yokes are available that operate from variable DC current, but most yokes used for industrial applications are either the 110 VAC type or the permanent magnet type.

Yokes which are energized with AC can be put on and removed from a specimen in the unmagnetized condition, and can also be used for demagnetizing as well as magnetizing. The permanent magnet types produce a weaker flux field, and are, therefore, somewhat limited in range of applications.

Yokes are used in a manner similar to using prods. The magnetic field produced is weaker, however, and it is recommended that the continuous method of magnetization and particle application be used. Typical tests are conducted as follows:

- Position the yoke on the specimen over the area to be examined.
- Energize the yoke (if electric type) and apply the magnetic particles.
- Examine for discontinuities before removing yoke and again after removing the yoke.
- Re-position the yoke over the same area (rotating the yoke about 90°), and repeat the test.

Ultravoilet Inspection Lights

The ultraviolet or "black" lights used in magnetic particle inspection with fluorescent particles, usually consist of a ventilated housing, a mercury vapor arc lamp, and a suitable optical filter. The filter is designed to filter out harmful short waves of light, and pass a maximum amount of wave lengths which activate the fluorescent dyes in the inspection medium. The dyes typically fluoresce with a brilliant green-yellow color which is highly visible

to the eye under normal subdued light inspection viewing conditions. Most portable, hand held "black" lights use a 100 watt "spot" mercury lamp. In stationary test set-ups, large 400 watt lamp units may be mounted permanently to the power unit.

The intensity of the black light at the point of inspection is a critical factor in a test, because the amount of visible light emitted from a fluorescent pigment is directly proportional to the amount of black light energy supplied to the test surface. For this reason, the lamps are checked frequently with a suitable light meter to verify that the light output has not diminished, and is adequate for use. Experience has shown that a black light intensity of 90 foot candles at the point of inspection is the minimum intensity suitable for locating fine indications, such as those resulting from grinding cracks or heat-treating cracks. Even at this intensity, it is assumed that most of the background light (room lighting, sunlight, etc.) has been excluded from the inspection area with the use of opaque curtains or a darkroom constructed for that purpose.

Following the magnetization of the test specimen and application of the fluorescent magnetic particles, the inspector proceeds with the examination for discontinuities with the black light as follows:

- Turn the current on the lamp, if not previously done, and allow a minimum of 5 minutes warm-up time (to allow the arc to stabilize and reach maximum intensity).
- Hold the lamp approximately 15 inches from the test surface, with the beam focused on the area under examination. The lamp should be held at such an angle from the surface of the specimen that reflection of the light into the eyes does not occur.

- Leave the lamp on during the entire test or working period; switching on and off shortens the life of the lamp.
- Observe for indication of discontinuities.

DETECTABLE DISCONTINUITIES

The basic function of magnetic particle testing is to identify the presence of discontinuities. The detection of any discontinuity is dependent on the sensitivity of the specific technique of magnetizing and applying particles, as related to the size, shape, orientation and location of the discontinuity. The only classifications of discontinuities that are meaningful in this regard are: (1) those discontinuities that constitute a break in the surface of the part (open to the surface), and (2) those which lie wholly below the surface (within the part.)

Surface Discontinuities

Surface discontinuities represent the largest group and those easiest to locate with magnetic particle testing. Surface discontinuities may seriously affect the service life of the part, and include such defects as fatigue and service cracks, seams, laps, quenching and grinding cracks, and shrinkage cracks which occur on the surfaces of castings, forgings and weldments. In most cases, such discontinuities are detected easily due to the strong and highly localized leakage fields which occur. The most favorable characteristics of a surface discontinuity for its detection are:

- depth of discontinuity approximately at right angles to surface

- width at surface is small with a minimum air gap
- length at surface is large with respect to its width
- depth approximately 5 times as deep as its opening at the surface

The relationship between the surface opening and the depth of the discontinuity has a significant effect on detectability. Surface scratches may be as wide at the surface as they are deep, and usually will not form a magnetic particle pattern. Fatigue cracks and fine grinding cracks may have depths less than 0.001", but because the surface opening are 1/10 of that value or less, they are readily detectable using the wet method. These two examples, illustrate the importance of surface opening to depth ratio for capability of detecting surface discontinuities.

Subsurface Discontinuities

Discontinuities lying wholly below the surface present a more difficult problem for detection. With respect to the serviceability of the part, however, whether such discontinuities represent serious defects or not depends on the nature of the discontinuity. Subsurface discontinuities may be small voids or non-metallic inclusions which lie near to the surface, and are present to some extent in all steel products. Such discontinuities produce weak leakage fields, and can only be found when located very close to the surface.

A more serious type of subsurface discontinuity may occur deep in heavy sections, in the form of subsurface lack of fusion or lack of penetration in welds; cracks in weld passes; or internal shrinks, slag inclusions or gas pockets in castings. Detection of such discontinuities depends on a strong flux field emerging at the surface of the specimen as a result of magnetic field distortion by

the discontinuity. This is illustrated in Figure 32-4-2. The "spread" of the emergent field increases with the depth of the discontinuity. As the "spread" increases, the emergent field becomes weaker until the magnetic particles are not attracted, and no indication appears. The size, shape and orientation of the discontinuity have a significant effect on the emergent field which is generated, but the depth (amount of metal between the discontinuity and the surface) is the dominant factor.

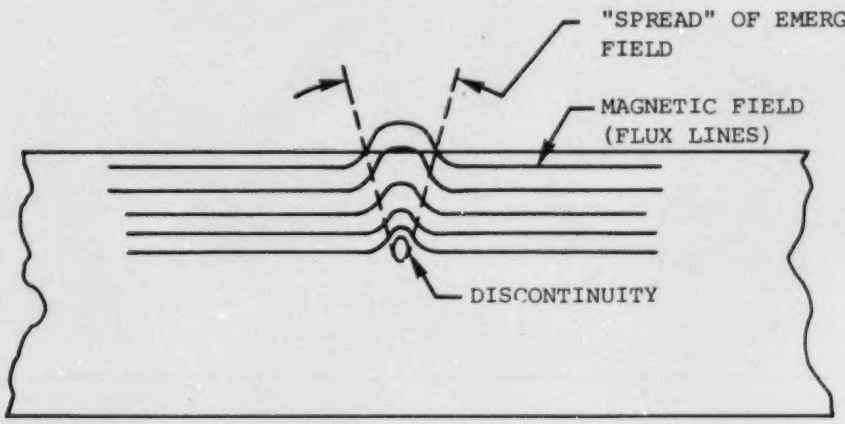

Figure 32-4-2 Spread of Emergent Field at a Discontinuity

In testing for deep-lying discontinuities, greatest test sensitivity can be obtained with the use of HWDC current magnetization and dry powder inspection medium. The "overall" method of magnetization (magnetizing entire specimen with high amperage current) produces optimum results for such tests, with the "prod" method and dry powder being the second choice.

A high degree of operator skill, however, even with an ideal test arrangement and procedure, is essential for success. The powder must be applied as a light, even, dust cloud, and observed carefully as it settles onto the part. Faint patterns, indicating leakage fields, may be formed as the first particles reach the surface, only to be obscured by additional particle accumulation. Excess particles must be blown very gently and carefully from the surface to re-establish a visible pattern. Even with great care exercised, the leakage field may be so weak that the particles indicating the pattern are also blown away.

NON-RELEVANT INDICATIONS

Definition

Indications which are formed by magnetic leakage fields but are not attributed to discontinuities or conditions that are relevant to the strength or useability of the part are considered non-relevant indications. Some of the common types of non-relevant indications are (1) external poles, (2) all-over patterns, (3) magnetic writing, (4) constructions, (5) cold working (6) dissimular metals, and (7) non-magnetic junctions.

External Poles

External magnetic poles may be created on parts at sharp corners, edges and ridges, and surface irregularities. Such poles are most likely to occur when longitudinal magnetization is used, and particularly when an excessive magnetizing force is applied. If the inspector has difficulty evaluating such indications, the part should be demagnetized, remagnetized at a lower level or in a different direction, and reinspected.

All-Over Patterns

When prods are used with an excessive magnetizing current to produce circular magnetic field in a part, indications of flux lines of the external field may be produced. This can be avoided by magnetizing at a lower power level. If the condition is extreme, it may be necessary to demagnetize the part, and then remagnetize at a lower level and reinspect.

Magnetic Writing

When parts come into contact with each other when either or both is in a magnetized condition, but not in the same degree, local poles may be formed at the areas of contact. One part may rub against the other in a random linear pattern. These magnetized "lines" attract magnetic partlces and resemble a fuzzy scrawl. The condition can be avoided by preventing parts from coming into contact with other magnetized parts. To eliminate "magnetic writing" from a part, the part needs only to be de-magnetized. The inspector may wish to then remagnetize the part and reinspect to verify that the condition was a non-relevant indication.

Constriction in Metal Path

Parts whose inside or back surfaces (relative to the surface inspected) are contoured, stepped, or otherwise sharply shaped differently from the surface inspected may show unwanted indications or outlines of these inside or back shapes when inspected, particularly when using circular magnetization. This may occur at the locations of internal gear teeth or splines or other characteristic areas where the magnetic flux lines are forced to the surface of the part because of constrictions or obstruc-

tions in the flux path. An experienced operator can easily relate such non-relevant indications to some cross-sectional or construction feature which accounts for the flux leakage-field. If the indication cannot be explained satisfactorily, the part should be demagnetized, and remagnetized and inspected at lower field strengths until the suspected non-relevant indications disappear.

Cold Working

Parts subjected to plastic deformation during cold working operations may exhibit nonrelevant indications when magnetic particle tested. These indications result from leakage fields caused by changes in grain structure and permeability in the parts. Cold working indications can usually be removed from a part only by heating the part above the curie point (transformation point at which a material becomes non-magnetic). The curie points for some ferromagnetic materials are listed in Table 32-4-5.

Table 32-4-5 Curie Points for Ferromagnetic Materials

Material	Curie Point, ^{o}C
Iron, 4% Maganese	715
Iron, 5% Silicon	720
Iron, 10% Chromium	740
Iron	770
Iron, 6% Vanadium	815

Welded Joints between Dissimilar Magnetic Materials

Steel materials which are different in hardness are also different in permeability. When any such dissimilar magnetic materials are joined by welding a magnetic leakage

field will be concentrated at that point where the permeability of the materials changes sharply. Magnetic particles will produce a nonrelevant indication along the junction lines, but do not provide any information about the soundness of the joint.

Brazed Joints

The brazing of the ferromagnetic materials consists of fusing the joints together with a film of brass. Since the brass materials is non-magnetic, a magnetic discontinuity is formed at the joint. When the area is magnetic particle examined, the joint is outlined with particles even though the joint is structurally sound.

DETECTION, INTERPRETATION AND EVALUATION OF DISCONTINUITIES

Types of Discontinuities

It is important that each specimen that is to be examined be considered as a unique part, and the test applied to produce the required sensitivity. The technician must consider the origin of the part, whether it has been in service, and the type of service and length of time to which it has been exposed. The origin of the part determines the type of discontinuities which may be expected.

Inherent discontinuities and processing discontinuties should be expected to occur for parts not yet in service. Inherent discontinuities are discontinuities related to the solidification of molten metal in wrought and cast metal products, and include gas porosity, shrinkage cracks, inclusions, and internal fissures. Processing discontinuities are those resulting from any of the various metal working processes such as machinery, welding, forming, rolling, heat treating, and plating.

Typical discontinuities which result from processing operations include seams, laminations, cooling cracks (hot-rolled products), forging bursts, and various types of discontinuities in weldments.

If the part has been in service for a period of time service discontinuities in the form of cracks may be expected. These include fatigue cracks and stress corrosion cracks.

Gas Porosity

Gas porosity may be trapped in cooled metal in a cast product, a weldment, or in the original ingot. Porosity is usually rounded or elongated in shape, and may be either scattered throughout the metal or isolated in small groups or clusters. Porosity may be entirely subsurface, or open to the surface. Magnetic particle examination may be used to detect porosity open to the surface, but subsurface porosity does not produce a clearly defined pattern suitable for reliable detection and evaluation. Preferrable examination for subsurface porosity is radiography.

Shrinkage Cracks

Shrinkage cracks, open to the surface, may result from rapid or uneven cooling of cast or welded metal. Such cracks may range from very small, shallow, and tight, to open and deep. When examining for such discontinuities, it is important to induce the magnetic field in at least two different directions. If small, tight discontinuities are present, they may not produce indications if they are oriented parallel to the magnetic field.

Inclusions

Inclusions may be metallic or nonmetallic, and be found in any shape and surface or subsurface. Metallic inclusions are particles of metals of a different density as compared to the base metal. In weld metal tungsten inclusions may be found where the tungsten-inert-gas welding process (TIG) was used. Non-metallic inclusions are oxides, sulphides, slag or other non-metallic foreign matter trapped in a weld or in cast or ingot metal.

Magnetic particle examination is useful only for detecting inclusions at or very near the surface. Indications of such discontinuities may appear jagged, irregularly shaped and not well pronounced. A preferable method for detecting inclusions is radiographic.

Internal Fissures

Internal fissures or voids may occur in ingots or casts as a result of shrinkage during cooling. When these occur in ingots, subsequent operations such as rolling may squeeze the sides of the void together and either fuse or weld the surfaces together (thereby eliminating the discontinuity, or create a "lamination" in the rolled product. Internal fissures usually cannot be detected with magnetic particle examination unless the void is very near to the surface examined. Radiographic examination is preferable for detecting internal fissures.

Laminations

Laminations are flat, planar discontinuities found in rolled plate or strip which are formed when internal voids are enlarged and flattened during the rolling operation. Such discontinuities are internal and lie in a plane

parallel to the surface. Unless the lamination runs out to the edge of the plate, or the lamination is exposed at the end of a cut plate, it usually cannot be detected by magnetic particle examination. When the discontinuity is exposed on an edge, however, magnetic particle examination of that area will readily detect the defect, and produce a sharp, clearly defined linear indication. Ultrasonic examination is the most reliable method for internal laminations, as they present a planar, reflecting surface.

Laps

Laps are linear discontinuities that extend to the surface of rolled bars and forgings. They have the appearance of tight, longitudinal cracks. Laps may occur during the rolling process, such as during the rolling of ingots into billets, as the result of over-filling of the rolls. The production of a typical lap is illustrated in Figure 32-4-3. Laps may be severe, may run the entire length of the billet, and may render the billet useless for some products. Laps are easily detected with magnetic particle examination, and produce sharp, distinct linear indications.

Excess Metal

(a) Over-filled rolls squeeze-out excess metal as shown.

"Lap" Formed

(b) Subsequent pass through the forming rolls squeezes the excess metal into an overlapping configuration as shown.

Figure 32-4-3 Production of Typical Lap

Seams

Seams are linear discontinuities that extend to the surface of rolled bars, and are formed in a manner similar to the formation of laps. Whereas laps are formed from over-filled rolls, seams are formed from under-filled rolls, as shown in Figure 32-4-4. Seams are usually crack-like discontinuities oriented nearly normal to the surface of the bar, and can easily be detected with magnetic particle examination.

Void or Depression

(a) Under-filled rolls leave a longitudinal void or depression in the billet as shown.

"Seam" Formed

(b) Subsequent pass through the forming rolls squeezes the void closed as shown.

Figure 32-4-4 Production of Typical Seam

Cooling Cracks

Cooling cracks are stress cracks that may occur in alloy steel bars due to the uneven cooling following roll-forming operations. Cooling cracks are usually longitudinal, variable in depth, and may be irregularly shaped rather than straight. Cooling cracks are easily detected with magnetic particle examination with the indications being stronger and more pronounced at locations where the crack is deepest.

Bursts

Bursts are irregular, internal cavities which may extend to the surface, that are found in wrought material which was forged, rolled, or extended. Bursts may result from forging material at too low a temperature, or from excessive working of the material during processing operations. Bursts may be large cavities, and are seldom healed or fused together during subsequent processing operations. Magnetic particle examination is only suitable for locating bursts at or near the surface of the part. Ultrasonic testing is usually used in examining for internal bursts.

Fatigue Cracks

Fatigue cracks are discontinuities which may occur in areas of stress concentration, such as fillets, splines, keyways, threads, oil holes, or holes for fasteners. Fatigue cracks usually begin as submicroscopic fissures and spread as a result of repeated stressing. Once started, a crack may progress quickly due to the increased stress concentration resulting from the crack itself. Fatigue cracks may ultimately lead to the failure of the part and are usually considered cause for rejection. Fatigue cracks are easily detected with magnetic particle examination, and from their, distinct hair-line indications.

Stress Corrosion Cracks

Parts which are exposed to a corrosive environment while under sustained tension in service may develop surface cracks known as stress corrosion cracks. This phenomena is more likely to occur faster at high levels of stress than at low levels, and may progress through the section until failure occurs. Although magnetic particle

examination may be used quite satisfactorily to detect stress corrosion cracks in ferrous materials, liquid penetrant is commonly used since this type of defect occurs in both ferrous and nonferrous materials.

Discontinuities in Welds

Magnetic particle examination is used extensively to detect surface or near-surface discontinuities in welds. The discontinuities found produce indications similar to those described above for similar types of discontinuities in other types of ferromagnetic materials. The discontinuities in welds include:

- porosity
- lack of fusion (produces indication similar to that of a crack)
- shrinkage cracks (from improper cooling or heat control)
- non-metallic inclusions, or metallic inclusions of a density different than that of the weld metal.

Discontinuities Introduced in Finishing Operations

Many times parts may be processed through manufacturing operations, free from all objectionable discontinuities, up to the point of finishing or final processing only to be damaged beyond repair during heat treating, grinding, machining, plating, pickling, or acid etching. The discontinuities produced are open to the surface, detectable with magnetic particle examination, and described as follows:

- Heat treating cracks - During the heating and cooling processes associated with heat treating, localized stresses may be induced by thermal imbalance. If the stresses exceed the tensile strength of the material, cracking occurs. Such

cracking usually occurs in areas of rapid material thickness change such as around keyways, grooves, basses, fillets and webs. These cracks are usually deep and forced, irregular in shape, and arranged in random patterns.

- Grinding cracks - Grinding cracks are surface cracks which are caused by stresses setup by localized heating under the grinding wheel. Grinding cracks are very shallow and resemble heat treating cracks. They usually occur in groups, and at right angles to the direction of grinding. Grinding cracks can be avoided by using proper grinding wheel, coolant, and rate of feed.
- Machining - Machining tears result when an article is worked with a dull tool or when an excessively deep cut is made. Metal is actually torn from the surface, and numerous short, surface discontinuities are produced.
- Plating - Plating cracks sometimes result from the plating process when plating with hardened materials. Such cracks are very thin and tight, and require careful examination to detect them.
- Pickling or acid etching - Hardened surfaces which contain residual stresses may crack when exposed to acids in the pickling or etching processes. The acid attack on the surface fibers of the material appears to trigger the cracking/stress relief action, and produces fine, irregular cracks.

EXERCISES

1. Fill in the blanks in the following statements:
   a. Magnetic particles may be applied by the _____ method or the _____ method.
   b. The _____ method is the method of applying the magnetic particles to the specimen with the magnetizing current turned off.
   c. The residual magnetization method can only be used effectively on specimens having _____ retentivity.
   d. Greater sensitivity can usually be obtained by applying magnetic particles with the _____ method.
   e. Maximum indications will be produced by discontinuities which lie _____ to the magnetic lines of force.
   f. It is usually recommended that a specimen be magnetized in at least _____ directions to provide adequate assurance of detecting possible discontinuities.

2. A longitudinal field is induced in a large test specimen by using a coil with 8 turns wrapped around the part. If a current of 800 amperes is passed through the coil, what magnetizing force is applied (in ampere-turns)?

3. A test specimen is a solid bar measuring 20" long and 4" in diameter.
   a. What is the L/D ratio of the specimen?
   b. Does the resulting L/D ratio indicate that the part is suitable for coil magnetism?
   c. Calculate the current required for magnetizing the speciment with a 5-turn coil.

4. In magnetizing a part using prods, what is the recommended current range using a prod spacing of 7 inches or ½" thick material?

5. What basic types of current output are usually available on portable, mobile, and stationary magnetic particle power units?

6. Stationary units are usually used with what method of magnetic particle application/inspection?

7. The settling test is used for what purpose?

8. What method of demagnetization is easiest to use?

9. What is the recommended minimum black light intensity at the point of inspection?

10. What physical phenomenon is required on the surface of a test specimen to detect a discontinuity with magnetic particle examination?

11. What is the most sensitive method for examining for deep-lying discontinuities by magnetic particle examination?
    current _____
    inspection medium _____

12. External poles, constrictions in metal path of test specimens, joints between dissimilar metals, and cold working operations may produce _____ in parts examined.

13. Residual magnetism in a specimen may be removed by heating it to its _____.

14. List the three basic classifications of discontinuities as related to their origin:
    a. _____
    b. _____
    c. _____

MATERIALS

The following materials are required to support this module.

1. Portable or mobile power supply unit, with variable outputs for HWDC and AC current
2. Portable, electromagnetic yoke (110V AC types)
3. Portable, permanent magnet yoke
4. Black light inspection lamp

5. Inspection media:
   - Red and black dry powders
   -*Red wet-bath suspension powder and solvent
   -*Fluroescent wet-bath suspension powder and solvent
6. Demagnetizing coil (110V AC type)
7. Inspection media applicators
   - Dry powder squeeze bulb
   - Wet-bath hand sprayer
8. Light meter for checking black light lamp output
9. Magnetic field indicator
10. Test speciments with typical defects or discontinuities.

*These materials may be obtained pre-mixed and packaged in aerosal cans.

PROCEDURES

1. Obtain from the instructor a part to be inspected and prepare an inspection procedure for examining the part by magnetic particle testing. Include:
   a. Type and value of current
   b. Type of magnetizing apparatus
   c. Magnetizing method
   d. Type of particles
   e. Method of particle application
   f. Demagnetization method
2. Examine the part supplied for Procedure #1 using the developed procedure.

3. Examine the part supplied for Procedure #1 using different magnetizing methods and compare results with the original method.

DATA TABLE

None.

REFERENCE MATERIALS

Betz, C.E., Principles of Magnetic Particle Testing, Magnaflux Corporation, Chicago, Illinois.

Libby, Hugo L., Introduction to Electromagnetic Nondestructive Test Methods

McGonnagle, Warren J., Nondestructive Testing, New York, McCowan Hill Book Company

Metals Handbook, Volume 11, Nondestructive Inspection and Quality Control, American Society for Metals

Nondestructive Testing Handbook, edited by Robert C. McMaster, Ronald Press

TEST

1. Name two methods for applying magnetic particles and relate their relative sensitivities.

2. Relate the orientation between magnetic field and discontinuity with the ability to detect the discontinuity.

3. State the thumb rule for determining current values for magnetic particle examination by circular magnetization of bars with:
   a. Half wave direct current:

   b. Alternating current:

4. What L/D ratio range is best for longitudinal magnetization of small parts?

5. Calculate the current for longitudinal magnetizing a tubular product whose length is 15 inches and diameter is 3 inches using a 10 turn coil.

6. State the recommended range of spacing of prods used for magnetic particle examination.

7. State the rule of thumb for determining current for magnetic particle testing with prods.

8. Name three types of power units used in magnetic particle examinations.

9. Briefly describe the conduct of a dry powder magnetic particle examination of a flat surface using a portable unit and prods. Include setting of current, spacing of prods, orientation of prods, and application of particles.

10. Briefly describe the conduct of a wet fluorescent magnetic particle examinations of a valve stem using (a) head stocks and (b) coil. Include setting of currents, application of particles, and observation for indication.

a.

b.

11. State the purpose of a "settling test" with respect to magnetic particle examinations.

12. Relate the location of discontinuities with respect to material thickness and the ability of magnetic particle examination to detect the continuity.

13. What is more easily detected by magnetic particle examination: shallow, open surface discontinuities, or tight, deep surface discontinuities.

14. Describe the importance of knowing the origin of various types of discontinuities.

15. Name any four discontinuities, state their origin, and describe the relative ability of their detection by magnetic particle examination.